

X- and K-Band Maser Development: Effects of Interfering Signals

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Signals at levels exceeding -90 dBmW at the input connection of a traveling-wave maser can affect maser performance in a variety of ways. Both S-band and X-band masers are considered where interfering signals are: (1) within the maser bandpass, (2) near the maser bandpass, and (3) far from the maser bandpass, where mixing with the maser pump can occur.

I. Interference to Maser Operation

Signals at levels exceeding -90 dBmW at the input connection of a traveling-wave maser (TWM) affect maser performance in a variety of ways, depending upon the amplitude and frequency of the interfering signal. The particular masers considered here are the S-band Block III (2270-2300 MHz) and the X-band (8400-8500 MHz) TWMs.

The first situation considered is where a signal exceeding -90 dBmW is at a frequency located within the maser signal bandpass. The -90 dBmW signal is amplified by the maser (net gain = 45 dB) and leaves with an amplitude of -45 dBmW in the normal manner. Signal levels greater than -85 dBmW cannot be amplified by the same amount (45 dB) because the output level would exceed -40 dBmW. The maser material spin system is in an inverted population condition to provide amplification; typically the population inversion begins to degrade at a TWM output signal level of -40 dBmW and the maser gain therefore decreases. This gain loss is referred to as maser saturation.

The presence of a saturating signal in the maser bandpass does not necessarily produce intermodulation products during the amplification process of another signal within the bandpass. A demonstration involving two large signals within the maser bandpass (partially saturating but not completely eliminating maser gain) produced no detectable intermodulation products. The signals were spaced 1 MHz apart in frequency and the measurement of resolution extended 60 dB below the level of the test signals. The ability of a large, saturating signal to produce intermodulation in a maser depends on its proximity to other signals. The difference frequency between the two interfering CW signals must have a period that approaches the spin relaxation time involved in the maser process (typically 0.05 sec) in order to cause substantial intermodulation. A large (partially saturating) signal with low frequency amplitude modulation (less than 10 kHz AM) is capable of modulating the maser gain at the AM rate, thereby transferring the AM to other signals in the maser bandpass. Excessive reduction in maser gain caused by a large interfering signal degrades the system noise temperature; this occurs at first as an increase in the effective input noise temperature contribution of the amplifier or receiver behind the maser.

The second situation considered involves signals near the maser bandpass. Maser saturation occurs as a function of signal level and frequency separation between the maser bandpass and the interfering signal. Safe levels vary from -90 dBmW at the band edge to -30 dBmW when the signal is removed by 100 MHz from the maser band edge. This sensitivity to saturation occurs in a manner that can be approximated to be decreasing at the rate of 0.6 dB/MHz for the first 100 MHz and then at a lesser rate of 0.1 dB/MHz for the next 300 MHz. In general, at frequencies more distant than 400 MHz from the band edge the maser performance is not disturbed by signal levels lower than 1 mW. At levels above 1 mW heating can reduce maser gain in proportion to the power level of the interfering signal.

An exception to the general insensitivity of the maser to out-of-band interfering signals is the third situation considered. Out-of-band signals mixing with the maser pump or pumps (dual pumps are used at X-band) can cause interference at the signal frequency and maser gain reduction. Masers are pumped at frequencies required by the paramagnetic energy level system at power levels of 0.1 watt (nominal). Pump energy is supplied by free-running klystrons or gunn oscillators which are frequency modulated at rates of 20 to 120 kHz with frequency deviations as great as 220 MHz (see Table 1). The difference frequency between maser pump and signal frequencies is referred to as the idler frequency; electron spin resonance in the maser material occurs at the idler frequency (or frequencies). Masers are particularly susceptible to interfering signals at the idler frequency. Interfering signals at the

maser idler frequency result in a complete loss of maser gain when amplitudes are greater than -10 dBmW.

At lower levels maser gain reduction occurs and mixing produces interfering signals at the difference frequency between the idler interference signal and the frequency modulated maser pump. At idler interference levels below -40 dBmW the maser gain remains normal, but mixing occurs with a conversion loss of 90 dB. For example: in an S-band maser a -40 dBmW signal at 10.4 GHz will mix with the 12.7 GHz maser pump, producing an interfering signal at 2300 MHz with a level of -130 dBmW when referred to the maser input. This mixed product will be frequency modulated (like the maser pump) and may appear as broadband noise on an ordinary spectrum analyzer. Safe levels for interfering signals at the maser idler frequency depend upon the overall receiving system sensitivity and should be computed with regard to the information given above. Measurements at +10 dBmW have resulted in detectable maser gain reductions at frequencies within 200 MHz of the idler frequency. Other mixing in a maser structure is noticeable when signals are introduced at levels above +10 dBmW at frequencies that could mix, or multiply and mix, with the maser pump. This mixing phenomenon is not believed to be caused by the maser material. Resonance isolator material and joints involving oxide layers which could form tunnel junctions in the maser structure can provide the nonlinear elements needed for this mixing phenomenon (Refs. 1 and 2). Maser signal frequency ranges, pump ranges, idler ranges and some typical candidate ranges for mixing due to nonlinearities are shown in Table 1.

References

1. W. Higa, R. Clauss, P. Dachel, "Low Noise Receivers: Theory of "Noise Bursts" on Large Antennas," in *The Deep Space Network Progress Report for March and April 1973*, California Institute of Technology, Jet Propulsion Laboratory, Technical Report 32-1526, Volume XV, pp. 80-83, June 15, 1973.
2. R. C. Clauss, "Low Noise Receivers, Microwave Maser Development, Second-Generation Maser," in *The Deep Space Network Progress Report for the period May 1 to June 30, 1968*, California Institute of Technology, Jet Propulsion Laboratory, Space Programs Summary 37-52, Vol. II, pp. 58-61, July 31, 1968.

Table 1. Maser signal, pump, idler and mixing ranges

Maser signal frequency range	2270-2300 MHz	8400-8500 MHz
Maser pump frequency range	12.65 to 12.73 GHz	19.15 to 19.28 GHz ($f_{p\ 3-4}$) and 23.96 to 24.18 GHz ($f_{p\ 1-3}$)
Maser idler frequency ranges	10.35 to 10.46 GHz ($f_p - f_s$)	10.65 to 10.88 GHz ($f_{p\ 3-4} - f_s$) and 15.46 to 15.78 GHz ($f_{p\ 1-3} - f_s$)
Mixing ranges due to nonlinearities (typical)	14.92 to 15.03 GHz 7.46 to 7.52 GHz	27.55 to 27.78 GHz 32.36 to 32.68 GHz